

Supplier selection and evaluation decision considering environmental aspects

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Abstract.

Supplier assessment is widely studied in the literature as it is an important means of managing supplier relationships. Based on literature results our paper examines the extension of the vendor evaluation methods with environmental, green issues. This generalization means an extension of the traditional criteria and weight system of the supplier evaluation methods.

As green issues are getting recognition in purchasing and supply management, the literature is rapidly growing on how to develop green supplier evaluation systems. Studies focus on evaluation criteria and on evaluation methods. Since the 90's the environmental criteria were widely investigated. Evaluation methodology also receives substantial attention in literature: several assessment methods were developed to incorporate green aspects in supplier management decisions. However it is still the weighted points method, which is mostly used by practitioners.

In our paper the method of Data Envelope Analysis (DEA) is used to study the extension of traditional supplier selection methods with environmental factors. The selection of the weight system can control the result of the selection process. Our goal is to choose such weights which affect the results of the selection process. In this method we divide the criteria in two manners: the traditional and environmental (green) factors. Then with the help of DEA we are searching a weight system with which the environmental criteria can influence the decision with a representation of the green factors. In our study we look for a weight system to determine the environmental factors, as an important decision factors. To choose the mentioned weight system, we apply DEA (Data Envelopment Analysis) with common weights analysis (CWA) method. In this case of DEA/CWA the common weights are calculated with a linear programming problem. The classical DEA requires to solve so many linear programming, as the number of the decision making units, but method DEA/CWA requires only one programming model.

Keywords: Green supplier assessment, DEA, Common weights analysis, Multi-criteria decision making

Absztrakt.

A dolgozat a beszállító értékelés kiterjesztését tárgyalja a fenntarthatóság figyelembe vétele mellett. A súlyozott pontrendszer módszerének hiányosságai miatt más módszerek felé irányul.

A DEA módszerén alapuló common weights analysis (CWA) rendszert ajánljuk a beszállítók összehasonlítására. Ez abban különbözik a klasszikus DEA-tól, hogy ekkor minden beszállítót egyenlően vesszük figyelembe a hatékonyság megállapításánál. Ez teszi lehetővé, hogy közös súlyokat állapítsunk meg.

Kulcsszavak: Zöld beszállító értékelés, DEA, Common weights analysis (CWA), Többkritériumos döntés

1. Introduction

Firms realise that it is not enough to consider and develop only their own performance as environmental issues getting more recognition in business. In a supply chain context green management covers performance of the whole chain which calls for the consideration of the environmental performance of the suppliers as well. The means of supplier management have gone through a major development over the last 20 years. Large number of studies was carried out which focus on supplier assessment, as the performance management of suppliers called for more sophisticated solutions for evaluation and measurement.

The supplier selection methods are widely examined in the literature with multi-criteria decision analysis models. These models contains such techniques, as analytic hierarchy process (AHP), analytic network process (ANP), or data envelopment analysis (DEA) etc. (Agarwal et al. 2011)

Investigations focus on the environmental aspects of the supplier selection and evaluation among them a number of papers try to build in green criteria into the criteria of supplier assessment. (Noci, 1997, Humpreys et al. 2003) Only few examinations (e.g. Selos, Laine 2012) relate to such situation, when it is not possible to use sophisticated methodology e.g. because the lack of strong mathematical background.

The aim of this paper is to contribute to sustainable supplier assessment methods. In our analysis we introduce the green criteria such as carbon emission in the supplier evaluation and we examine effect of changes on the selected supplier and on bid evaluation. Most of the methods use a kind of weight scores analyses. In our model we have chosen one of the multi-criteria decision-making methods namely the Data Envelopment Analysis (DEA). The proposed model helps the decision maker (purchaser) to compare the bids and to consider the

effects of changes of the bids. The proposed model also helps group decisions to consider the effects of the different values of the group members (e.g. financial and environmental aspects).

This paper will be organised as follows. First a brief literature review will be provided on supplier assessment criteria, methods of green assessment and the categorisation of supplier. After the literature review a case example will be analysed. The Data Envelopment Analysis is applied to investigate the effects of environmental criteria in decision making processes. In our example the changes in the role of environmental criteria (e.g. carbon emission and recycling) will be compared. It will be examined that how the change of carbon emission in the supplier offer will affect the relative weight factors. In our example we analyse only one decision making units to demonstrate the functioning of the basic DEA model. In the classical, basic DEA model the decision maker must solve so many linear programming model, as the number of the decision making units. Then we present the common weights analysis (CWA) method. In this model we must solve only one linear programming model, which essential reduces the computation time to determine the efficient decision making units. Last, the result of the paper will be summarised.

2. Supplier assessment aim, criteria, portfolio analyses

The literature on supplier evaluation, vendor assessment and supplier certification is extensive (e.g. Araz, Ozkarahan, 2007, Ho et al., 2010, Simpson, et al, 2002, Talluri, Narasimhan, 2010) although terminology is not always defined how these terms relate to each other. In this paper the term ‘supplier assessment’ will be used, in a sense that it is a management activity with the primary aim of acquiring information to analyse and to manage supplier relationships and supply situations. Within this aim Stannack and Osborn (1997) identified three important

objectives or purposes, some of which may be contradictory. They identified these as: assessment for selection (to choose the best supplier); assessment for control (management and planning) and assessment for development (supplier ranking is clearly useful as a motivational tool). Assessment for selection is perhaps the most commonly known form, however as purchasing management is playing a rather proactive than reactive role the other two aims are getting more attention. The review of literature of supplier assessment will cover 3 topics: first how the assessment criteria evolved, how environmental aspects can be incorporated in the evaluation, second the evaluation methods of green supplier assessment, third to highlight the diversity of purchasing situations purchasing portfolio methods will be referred to and their implication on supplier assessment.

2.1. Systems of criteria of supplier assessment

Supplier assessment rests upon the development of criteria. These criteria will be embedded in the environment in which they are developed. The most common assessment criteria have changed over time. According to Dickson (1966) the most important categories in the 1960s were the quality, delivery, performance history, warranties and claim policies, production facilities and capacities, price, technical capability, financial position. A later study of Weber et al. (1991) ranked quality as of extreme importance, net price, delivery, production facilities and capacity, technical capability, financial position, performance history, warranties and claims as of important criteria. It was just later that environmental factor as part of assessment criteria were discussed. Since the mid 90' several studies were published with the aim of providing a structured picture of assessment criteria. Noci (1997) suggested a preliminary framework that identifies 4 groups of measures for assessing environmental performance as green competencies, current environmental efficiency, supplier's green image and net life

cycle cost. Handfield et al. (2002) identified as the top 10 most important criteria to measure supplier's environmental performance as

1. public disclosure of environmental record,
2. second tier supplier environmental evaluation,
3. hazardous waste management,
4. toxic waste pollution management,
5. on EPA 17 hazardous material list,
6. ISO 14000 certified,
7. reverse logistics program,
8. environmentally friendly product packaging,
9. ozone depleting substances,
10. hazardous air emissions management.

They have also ranked the top 10 most easily assesses criteria 1. ISO 14000 certified, 2. Ozone depleting substances, 3. Recyclable content, 4. VOC content, 5. On EPA 17 hazardous material list, 6. Remanufacturing/reuse activity, 7. Returnable or reduced packaging, 8. Take back or reverse logistics, 9. Participation in voluntary, EPA programs, 10. Public disclosure of environmental record.

Humphreys et al. (2003) also developed a framework for incorporating environmental criteria into the supplier selection process. In their construct they identified quantitative (e.g. environmental friendly material, environmental costs), and qualitative environmental criteria (e.g. management competencies, green image, design for environment).

These studies exemplify that researchers formulated frameworks for comprehensive assessment of suppliers. The frameworks provided by them support supplier selection; however they can be used for the other two goals of assessment: they might serve control and development purposes as well. These models provide support to overview critical aspects of supplier performance, however they seldom help the selection process (the identification of the decision criteria). Our paper will close this gap as it highlights the role of weights in decision process.

2.2. Methodology of supplier assessment

The methodology supplier assessment receives substantial attention in literature. Papers are diverse according to their aims and to the applied mathematical instruments. Several assessment methods were developed to incorporate green aspects in supplier management decisions, in this paper only a few of them is featured. Beside the classical supplier evaluation methods (the categorical method, weighted-point method) Noci (1997), lists the matrix approach, vendor profile analysis and Analytic Hierarchy Process. Enarsson (1998) used the fishbone diagram as an evaluation tool. Araz and Ozkarahan (2007) developed a new multicriteria sorting method based on Promethee methodology, Liu et al. (2000) proposed a methodology for effective supplier performance evaluation based on data envelopment analysis technique. Narasimhan et al. (2001) proposes a methodology for evaluation to assist supplier development, with the help of DEA they identify supplier clusters. Hsu and Hu (2009) present an analytic network process (ANP) approach to incorporate the issue of hazardous substance management (HSM) into supplier selection. Bai and Sarkis (2010) also aims to help supplier development by introducing a formal model using rough set theory to investigate the relationships between organizational attributes, supplier development program

involvement attributes, and performance outcomes. In their model the performance outcomes focus on environmental and business dimensions.

The above referred literature provides frameworks with comprehensive solutions. This implies that incorporation of environmental criteria in supplier selection often calls for sophisticated methodology. In most of the cases the assessment process each time it is completed requires the assessors (or at least one expert) to have deep mathematical knowledge.

2.3. The diversity of the purchasing situation and its implication to the assessment

One of the most important statements of literature on purchasing and supply management is that supply situations are not alike. A number of portfolio models try to provide structures to evaluate the supply situation or the position of the buyer. They also call attention to the distinct management of the diverse situations. Perhaps the most well-known method is the Kraljic matrix (Kraljic, 1983), which categorises the purchased items in to four groups according strategic importance of the item and the complexity of supply market (many author uses the matrix with the factor of supply risk instead of the complexity of the supply market). A similar model was developed by van Weele (2009), who provided a structured management approach to each four categories. The matrix of Bensaou (1999) is also frequently referred in the literature, in which the structuring factors are the supplier specific investments of the buyer and the buyer specific investments of the supplier. The environmental aspects are not explicitly involved in these portfolios; however they can be easily incorporated in the dimensions. (E.g. it can be considered to be a form of supply risk.) There is an enhanced version of the Kraljic matrix (Krause et al. 2009), which deals with the incorporation of

sustainability criteria and calls attention to diverse approach and management attention to the categories.

Beside diverse purchasing situations there are other factors e.g. company size, which may influence the purchasing practice of a company. Literature draws a distinction between a person (shopping) and an organisation or a firm (buying) acquires goods and services. (van Weele, 2009) The purchasing processes of firms are based on rationale logic, sophisticated methodology (e.g. application of the above methodology) and the decision is in most of the cases made by a group. The purchasing courses and publications mostly focus on their practice, they are capable to apply the above mentioned sophisticated management tools of supplier assessment. There is another group of companies, (beside shoppers and buyers) referred as a third group (Tátrai, Vörösmarty, 2010). The small and medium sized companies (SME) because of their size and processes are organisational buyers (as they make purchasing decisions based on rational management criteria), however in most of the cases it is not possible for them to use the sophisticated purchasing methodology e.g. they do have the know-how or the organisational specialisation of the large companies. Because of the large number of these companies and the importance for the economy many recent studies focus on the practice of SME and many of them investigate their purchasing practice (Ellegaard, 2009, Knudsen, Servais, 2007, Morrissey, Pittaway 2004). As these firms in most of the cases are not capable to use sophisticated management tools, e.g. they are not able to use sophisticated methodology for assessing the environmental activity of the suppliers.

2.4. Summarizing the result of literature

The above brief review of literature was intended to highlight that there is a gap in research interests in two fields. First they miss to highlight carbon emission as an important supplier

selection criterion. Second, most of the research in the topic of how to incorporate environmental aspects into supplier assessment focuses on the high importance purchasing situations or suggest a methodology which requires deep mathematical knowledge.

This paper suggests that the overall impact of those situations when the purchasing is not important or the risk is not high is significant and should be considered. Especially in a number of cases it is not possible or affordable to use currently available complex (perhaps time consuming or costly) methodologies. This is mainly why in practice it is still the weighted points method, which is mostly used by practitioners to assess the performance of suppliers. Beside the methodological weaknesses (as subjectivity of weights, incoherent measurement) weighted point method has several advantages from practical point of view: it is easy to understand the calculation, requires only basic mathematical knowledge, and quickly provides output.

3. DEA Framework for weight selection

Because of its easy usage the weighted point model is of practical importance in purchasing management. It makes it relevant to investigate its applicability. The selection of weights in most of the cases happens in advance as part of a group decision; however very often reflect subjective judgement. One of the most important limitations of this method that weights for various supplier performance attributes used in the weighted, additive scoring model are arbitrary set (Narasimhan et al. 2001). Thus the final ranking of the supplier is heavily dependent on the assignment of these weights, which are often difficult to specify in an objective manner. In this section with the help of DEA we intended to develop a framework to assist the selection of the weights in a way to allow the control the result of the selection process. Our goal is to choose such weights which affect the results of the selection process.

The supplier selection model is formulated, as a decision making problem. Let us assume that the suppliers are evaluated along management and environmental criteria. The management criteria are the usual supplier evaluation criteria, such as trustworthiness, purchasing price, lead time, or quality of the supplied products etc. The environmental criteria are listed in the last section of this paper. We assume that the environmental criteria are the outputs of the examined model. A very common method is used to investigate the effects of environmental issues on the supplier assessment.

3.1. The application of the basic DEA model in supplier selection

Let us assume that the purchaser evaluates $p+1$ suppliers. The number of traditional management criteria is n and the number of environmental criteria is m . The evaluation of supplier i is defined with vectors $(\mathbf{x}_i, \mathbf{y}_i)$, where vector \mathbf{x}_i is the value of the management criteria and vector \mathbf{y}_i is the environmental criteria.

Method DEA is a general framework to evaluate suppliers in materials and supply management in the absence of weights of the criteria. The application of method DEA is based on the categories “inputs”, “outputs”, and, efficiencies. The basic method was initiated by Charnes et al. (1978) to determine the efficiency of decision making units (DMU). The model offered by them is a hyperbolic programming model under linear conditions. A general solution method of such kind of models was first investigated by Martos (1964) who examined the problem as a special case of linear programming model. The aim of the DEA model is to construct the weights for the management (input) and environmental (output) criteria. The weights are vectors \mathbf{v} and \mathbf{u} for the management and environmental criteria.

Let us formulate the DEA model in the next form, assumed that we examine the efficiency of the 0^{th} decision making units:

$$\mathbf{u} \cdot \mathbf{y}_0 / \mathbf{v} \cdot \mathbf{x}_0 \rightarrow \max \quad (1)$$

s.t.

$$\mathbf{u} \cdot \mathbf{y}_j / \mathbf{v} \cdot \mathbf{x}_j \leq 1; j = 0, 1, 2, \dots, p. \quad (2)$$

$$\mathbf{u} \geq \mathbf{0}, \mathbf{v} \geq \mathbf{0}. \quad (3)$$

Model (1)-(3) is the basic model of the method DEA which can be reformulated in a linear programming model in the following form:

$$\mathbf{u} \cdot \mathbf{y}_0 \rightarrow \max \quad (4)$$

s.t.

$$\mathbf{v} \cdot \mathbf{x}_0 = 1, \quad (5)$$

$$\mathbf{u} \cdot \mathbf{y}_j - \mathbf{v} \cdot \mathbf{x}_j \leq 0; j = 0, 1, 2, \dots, p. \quad (6)$$

$$\mathbf{u} \geq \mathbf{0}, \mathbf{v} \geq \mathbf{0}. \quad (7)$$

Model (4)-(7) can be solved with commercial software, e.g. with Microsoft Excel Solver.

Throughout the paper we apply this software to construct our numerical examples.

Management criteria	1	2	3
Lead time (Day)	2	1	3
Quality (%)	80	70	90
Price (\$)	2	3	5
Environmental criteria			
Reusability (%)	70	50	60
CO2 emission (g)	30	10	15

Table 1. Data for numerical example

Let us transform the data of the table 1 in that form that a better result of a criterion is higher than that of a worse evaluation. If a better criterion has a higher value, than we do not change the evaluation of that criterion. (It is the case e.g. for the reusability, lead time and price.) If the better criterion gets a lower value, than we have two methods to build in the table: either we choose a negative sign before the given data, or we use the inverse of the data. In our analysis we have chosen the second solution to handle this problem. The new, transformed table is now:

Management criteria	1	2	3
Lead time (Day)	2	1	3
Quality (%)	1/80	1/70	1/90
Price (\$)	2	3	5
Environmental criteria			
Reusability (%)	70	50	60
CO2 emission (g)	1/30	1/10	1/15

Table 2. The transformed data

The linear programming model has the following solution for the first supplier.

Lead time	Quality	Price	Reusability	CO2 emission
0.1964	0.0021	0.3036	0.0143	0.0

Table 3. Solution of the DEA model for the first supplier

In our numerical example two set of criteria were formulated: management (traditional purchasing criteria) and environmental criteria.

The weights vector suggests that the weight of lead time and price aspects should be neglected in the evaluation of the suppliers. The reusability aspect received higher weight, than other criteria. In this evaluation situation the reverse logistic subsystem of the vendor should receive such a high weight to influence the selection decision.

In this numerical example it was presented that CO₂ emission is so high that it is not decision relevant, i.e. the weight of this factor does not influence the selection process. Let us investigate the CO₂ emission of the first supplier as a parameter. In this sensitivity analysis it was examined that how high CO₂ emission level will be decision relevant. This means that the CO₂ level was parameterized in the linear programming.

Figure 1 shows the function of the factor weight in dependence on the carbon emission levels. This function is a decreasing one, which points out how lowering carbon emission level influence decision.

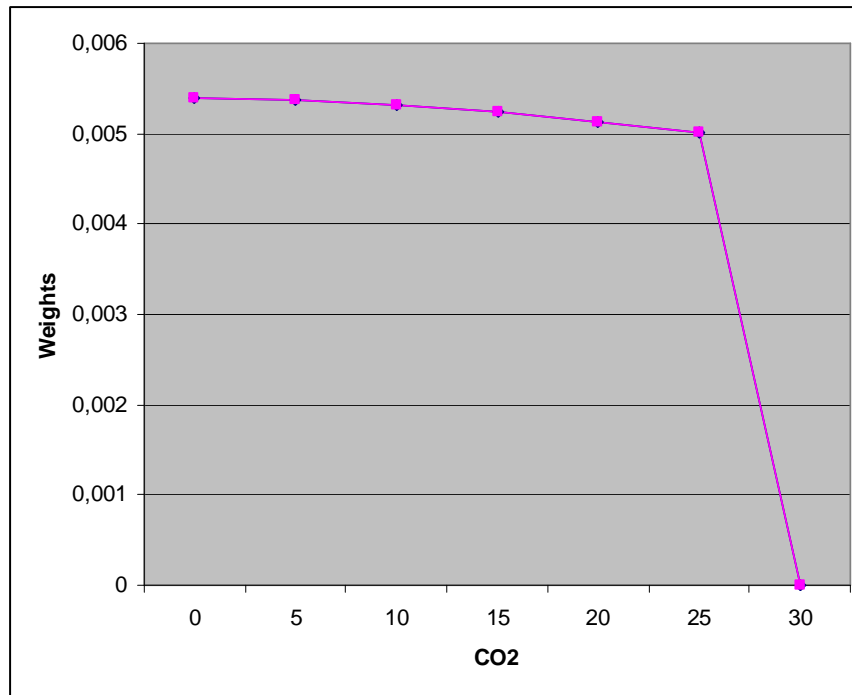


Figure 1. Decision weight factors in dependence on carbon emission

The second and third supplier has the next weights if their efficiency index is maximized. The scores are presented in table 3 below.

	Lead time	Quality	Price	Reusability	CO2 emission
Supplier 2	1.0	0.0	0.0	0.02	0.0
Supplier 3	0.0	90	0.0	0.0056	10

Table 4. Solution of the DEA model for the second and third supplier

The example shows that the reusability criterion is effective in the measure of environmental effects.

3.2. The application of DEA/CWA in supplier selection

The fundamental problem of the basic, classical DEA model is that the weight system differs from decision making unit to other one, solving the linear programming problems. To handle this deficiency, a number of authors offer new DEA-type models. Roll és Golany (1993)

propose to use weight restriction models to look for a common weight. Kao és Hung (2005) apply the method of compromise programming to search for a possible weight system. Unfortunately, the proposed model leads to nonlinear parametric programming model, which can be difficult to solve with numerical methods. Considering the difficulty of the mentioned models, we follow another way.

The method of common weights analysis was introduced by Liu and Peng (2008), and Liu, et al., (2006). The method is widely discussed in the decision making literature. (E.g. Jahanshahloo et al. (2010)) In the next we present the functioning of this model.

Let us write the linear programming problem (4)-(7) for the case, when the sum of inequalities (6) is maximised. The problem (4)-(7) can be reformulated in the following form (4')-(7'):

$$\mathbf{u} \cdot \mathbf{Y} \cdot \mathbf{1} - \mathbf{v} \cdot \mathbf{X} \cdot \mathbf{1} \rightarrow \max \quad (4')$$

s.t.

$$\mathbf{v} \cdot \mathbf{1} = 1, \quad (5')$$

$$\mathbf{u} \cdot \mathbf{Y} - \mathbf{v} \cdot \mathbf{X} \leq \mathbf{0}, \quad (6')$$

$$\mathbf{u} \geq \mathbf{0}, \mathbf{v} \geq \mathbf{0}. \quad (7')$$

In problem (4')-(7') vectors $\mathbf{1}$ are the summation vectors with elements one, matrices \mathbf{Y} és \mathbf{X} are the input and output matrices of the decision making units in the following form

$$\mathbf{Y} = [\mathbf{y}_0, \mathbf{y}_1, \mathbf{y}_2, \dots, \mathbf{y}_p], \mathbf{X} = [\mathbf{x}_0, \mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_p].$$

Equality (5') guarantees the boundedness of the set of the weight. Inequalities (6') subsume the efficiency indexes. Goal function (4') summarizes the deviations from the maximal efficiency. The solution of problem (4')-(7') is the common weights for the supplier selection problem, but this problem is only the first stage of the ranking of the supplier. The next, second phase determines the efficiency of the decision making units (suppliers).

In the second phase of the evaluation of supplier, we write up the dual problem of problem (4')-(7'). In the dual problem (8)-(11) we use the shadow prices, as a measure of efficiency of decision making units. The dual problem now is:

$$\lambda' \rightarrow \min \quad (8)$$

s.t.

$$\mathbf{Y} \cdot \boldsymbol{\lambda} \geq \mathbf{Y} \cdot \mathbf{1}, \quad (9)$$

$$-\mathbf{X} \cdot \boldsymbol{\lambda} + \lambda' \cdot \mathbf{1} \geq -\mathbf{X} \cdot \mathbf{1}, \quad (10)$$

$$\boldsymbol{\lambda} \geq \mathbf{0}, \lambda' \in \mathbb{R}. \quad (11)$$

The optimal solution of problem (8)-(11) is shadow price $\lambda = [\lambda_0, \lambda_1, \lambda_2, \dots, \lambda_p]$. If we rank the shadow prices of the suppliers in a decreasing order, then the most efficient decision making unit is with the highest shadow price. With this method the supplier can be ordered after its efficiency. The benefit of this method is that we need not solve $p+1$ pieces of linear programming problems, only one, and the weights can be used for every decision making units.

Let us apply the DEA/CWA method for our numerical example. The optimal solution of problem which are the common weights (4')-(7') is shown in table 5:

Lead time	Quality	Price	Reusability	CO2 emission
0,001519	0,998481	0,0	0,000192	0,061662

Table 5. The DEA/CWA weights

The optimal solution of problem (8)-(11) with our data is zero which means that all decision making units have the maximal efficiency. In such a model all of the supplier must be involved in the second phase.

The optimal shadow prices which are the optimal solution of problem (8)-(11) are presented in table 6:

Supplier	Shadow price (λ_i)
1.	1
2.	1
3.	1

Table 6. The efficiency of the decision making units with shadow prices

As shown in table 6, we can not differentiate among the supplier, because the optimal shadow prices are equal to one. We notice that the result of our numerical example is fully accidental.

We can write a linear equation system (5'')-(7''):

$$\mathbf{v} \cdot \mathbf{1} = 1, \quad (5'')$$

$$\mathbf{u} \cdot \mathbf{Y} - \mathbf{v} \cdot \mathbf{X} = \mathbf{0}, \quad (6'')$$

$$\mathbf{u} \geq \mathbf{0}, \mathbf{v} \geq \mathbf{0}. \quad (7'')$$

But there does not exist always a nonnegative for this system. With this numerical example we have demonstrated the applicability of DEA/CWA method on supplier selection and evaluation.

4. Conclusion

Environmental criteria are widely used in supplier selection systems. In this paper we investigated the influence of weights on the selection decision. Our contribution with the example is that in certain situation some criteria should be much overweighed to allow real influence on the selection process. The presented numerical example explained how the changes of CO₂ emission level of a supplier effected the supplier's position in the assessment process.

The used method of DEA is based on commercially available linear programming software packages such as Microsoft Excel Solver. As it was mentioned in the literature review theoretic models of supplier selection incorporating environmental criteria are too complex for practical application. This is why they are not widely used in management practice. Our model offers an easy decision support tool to develop criteria and weight system of supplier evaluation.

A purchaser (decision maker) can influence a decision (supplier selection) with the choice of weight system. In our numerical example we can determine that the environmental criterion CO₂ is irrelevant in the decision process, so it can be omitted in the decision making.

In a next paper a sensitivity analysis can be carried out to demonstrate the usability this concept of multi-criteria decision making methods. With easy software program based on a Microsoft Excel Solver the effects of the change of purchaser's opinion can be applied to solve such kind of decision problems.

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